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An Integration-Friendly Regrowth-Free Tunable Laser

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***Abstract*—This paper presents a single-mode tunable laser operating in the L band. The facetless design, along with a regrowth-free fabrication that does not require high-resolution lithography techniques, contribute to make the laser a suitable candidate for monolithic integration with other components. Vernier tuning is demonstrated over a range of 47nm, with side-mode suppression ratio (SMSR) values over 30dB and a linewidth of 800kHz.**

I. Introduction

MODERN communication networks rely heavily on single-mode tunable lasers for multi-wavelength communication systems. Single-mode is often achieved by using grating-based lasers such distributed Bragg reflectors (DBR) lasers [1], sampled grating DBR (SGDBR) lasers [2], or distributed feedback (DFB) lasers [3]. However, such lasers often require multiple epitaxial growth steps and high-resolution lithography [4]. While regrowth-free DFB lasers have been reported [5], [6], they require holographic lithography that increases the cost compared to standard UV lithography. A regrowth-free alternative has been proposed as a means to achieve single mode, that is also based on standard UV lithography: the introduction of defects along the laser cavity to create intra-cavity resonance leading to single-mode operation. Such defects can be slots [7]. However, their reflection and transmission performance proved to be extremely sensitive to etch depth, thus requiring careful control and potentially reducing the fabrication yield [8].

Another limitation observed in single-mode tunable lasers is the presence of cleaved facets as reflective features providing feedback. Such cleaved facets, also present in some DBR or SGDBR lasers [9], [10], add significant constraints to the development of monolithic photonic integrated circuits (PICs), limiting the options as to where the light source can be positioned: if the laser relies on a cleaved facet, it has to be placed at the edge of the chip.

The device presented here is a regrowth-free facetless laser using multimode interference (MMI) couplers [11] to couple parallel cavities terminated by on-chip, gold-coated etched facets (metal on etched facet, MEF). The use of an MMI coupler makes it possible to allocate one of the MMI ports to the guiding of the laser output towards other components, making the monolithic integration of this device with other components, trivial.

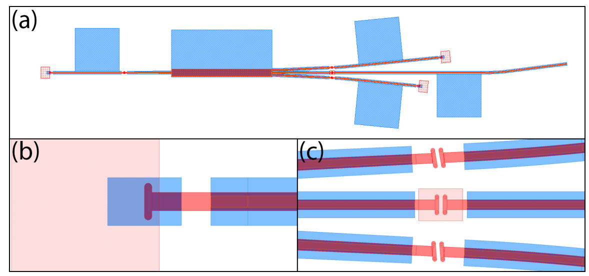

Fig. 1. (a) Schematic of the proposed design with details of (b) a MEF and (c) shallow isolation and deep reflective slots

II. Proposed design

The proposed design consists of a central 3x3 MMI coupler, to which several arms are connected. On one side, a single waveguide connected to the central port is terminated by a MEF and acts as a common section for the multiple cavities of the design. On the other side, a central arm acts as an output coupler and includes a reflective slot to provide a feedback boost, while two arms, also terminated by MEFs but of different lengths, are connected to the two outer ports. The two different lengths provide multiple cavity lengths that enable single-mode operation. The resulting design is presented in Figure 1. The output port was angled compared to the cleave plan to avoid any parasitic reflections from the cleaved facet during the characterisation process.

The 3x3 MMI coupler is 226µm long and 17µm wide. If an input signal is applied to the central port on one side of this coupler, this signal will be equally split between the three ports on the other side of the coupler, as described in [12]. As a result, it is also possible, under the right phase and amplitude conditions, to use this property to recombine three beams into a single port. An illustration of this case is presented in Figure 2. In the proposed design, achieving the optimal recombination conditions requires feedback from the output arm of the laser. This is why a reflective slot was used on this arm. However, because it is not a critical feature for single mode lasing, the slot depth does not require the careful control necessary for slotted Fabry-Perot single-mode lasers.

Through the use of on-chip etched facets and the availability of a waveguide to collect and direct the laser output to any other devices, the proposed design facilitates the monolithic integration of other components with the laser to obtain complex PICs at a reduced cost and process complexity [13].

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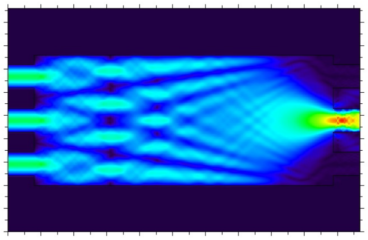

Fig. 2. Beam propagation simulation illustrating the combination of three input signals into a single output

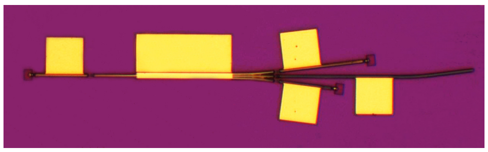

Fig. 3. Microscope photograph of a fabricated device

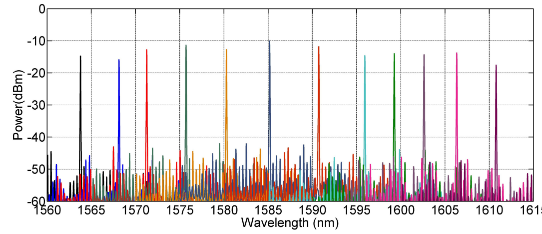

Fig. 4. Emission spectra of a 1x3 MMI/MEF laser for a 100μm cavity length difference

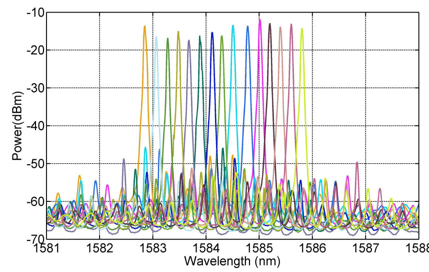

Fig. 5. Fine tuning of a 1x3 MMI/MEF laser for a 50μm cavity length difference

III. Fabrication process

The material used to fabricate the device was commercially obtained 1550nm laser material, grown on an InP substrate. It includes 5 compressively strained AlInGaAs quantum wells and does not involve any regrowth step in its construction. The fabrication process, similar to those presented in [14] and [15], is exclusively based on standard UV lithography. Using a combination of silicon oxide and silicone nitride layers as hard masks, it is possible to achieve two different etch depths, one immediately above the quantum wells to define the waveguides, and one below the quantum wells to improve the MEF and slot reflectivity. The metal contacts consist of Ti:Au (20:250nm) deposited by electron beam evaporation. They were patterned by the means of standard lift-off lithography, and the evaporation used a 360° tool to ensure adequate deposition on the side walls, especially on the MEFs. The resulting devices are presented in Figure 3. The use of an angled facet on the output arm allows the collection of the laser beam from a cleaved edge while limiting the reflected power, to avoid any interference in the characterisation of the device, but at the cost of a reduced output power.

With a simple fabrication process involving two etch depths and no advanced lithography techniques, the proposed devices are highly compatible with standard shared foundry processes [13]. With the integration-friendly geometry, they are good candidates as light sources for large-scale production of PICs.

IV. Characterization Results

The device was characterised on a temperature controlled brass chuck that was maintained constant at 20°C by the means of a thermoelectric cooler. The light output was collected from the angled output arm, through a lensed fibre to further reduce parasitic reflections that could disturb the analysis of the results.

A. Tuning Performance

The devices presented here achieved a tuning range of 47nm, from 1564nm to 1611nm. Adjusting the current in the independent arms defining the two different cavities result in a change to the optical path length of the arms. This allows Vernier tuning of the laser based on the interference between the arms, which adjusts the location of the preferred mode (referred to as the super-mode). The lasing spectra of a device at various bias configurations is shown in Figure 4, illustrating the achieved tuning range. The side-mode suppression ratio (SMSR) values for the spectra shown in Figure 4 were maintained above 30dB, reaching up to 33dB for the 1585nm lasing wavelength.

Fine tuning was also achieved by adjusting the bias of sections common to both cavities such as the MMI coupler or the common arm. Given the super-mode spacing inherent to the cavity length difference, the tuning range is related to the super-mode spacing: the shorter the length difference, the wider the spacing and the lower the tendency of the laser to switch to a different super-mode. As a result, wider local tuning ranges are achievable for smaller cavity length differences. In the case of a 50μm difference, a fine tuning range of up to 3nm was observed, while maintaining SMSR values above 27dB. An example of this tuning is illustrated in Figure 5.

B. Laser characterisation

The lasing spectra were processed by a Fourier analysis tool to study the spectrum and extract data on the cavities involved on the observed laser signal. Such an analysis is presented in Figure 6. The peaks on the graph correspond to the lengths of the cavities leading to the emitted spectrum. The two main peaks, at approximately 870μm and 970μm, correspond to the two cavities defined by the top and bottom arms of the laser. This 100μm length difference can also be observed at the 100μm peak. One can also observe minor artifacts at 560μm, 660μm and 760μm.

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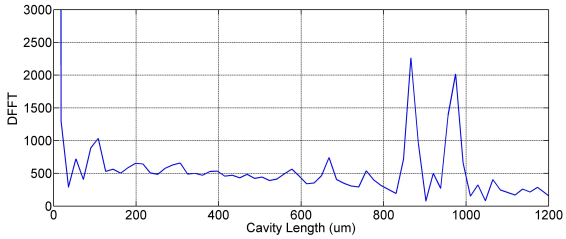

Fig. 6. Fourier analysis of the laser spectrum

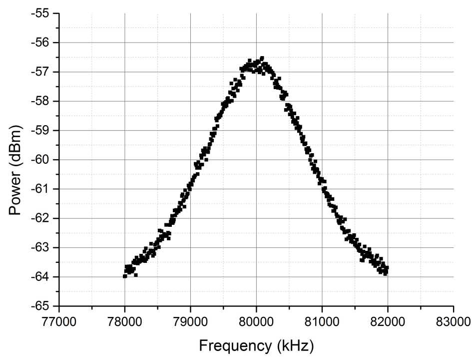

Fig. 7. Self-interference profile of the laser emission spectrum

The signal conditions for the MMI in [12] described relative values of phase and amplitude for correct recombination of the inputs into a single output beam. When these conditions are not met, light is present at the unallocated MMI ports, on each side of the common arm. In the absence of an output waveguide, this light is reflected back within the MMI, leading to the 560µm and 660µm reflections. Their combination with the 100µm length difference cause the artifact at 760µm. Indeed, these lengths correspond to the separation from the two MEFs to the opposite end of the MMI coupler.

The linewidth of the laser was measured using a standard self-heterodyne technique using a 50km fiber as delay [16]. The resulting self-interference profile shows a full-width at half-maximum of 1.6MHz, corresponding to a laser linewidth of 800kHz.

V. Conclusion

An MMI-based laser design was proposed and demonstrated. It can be fabricated from regrowth-free material, through a two-depth process that does not require advanced lithography techniques. The fabrication simplicity, along with the facetless design, make it a suitable canditate for monolithic integration into PICs. A Vernier tuning range of 47nm was achieved with SMSR values above 30dB, as well as fine tuning. The laser linewidth was measured to be 800kHz.

Acknowledgment

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